UNIVERSITY OF SASKATCHEWAN
ELECTRICAL ENGINEERING
EE313.3 ELECTRICAL MACHINES I
FINAL EXAMINATION

Instructor: N. Chowdhury **December 1997**
Time: 3 hours
Notes: **(a) This is a closed book examination.**
(b) Formula sheets are attached.
(c) Record in your answer book(a) all necessary steps and calculations.

Marks

15 1. The open-circuit characteristic data of a dc shunt generator taken at 1400 r.p.m. are shown below:

Field current (A)	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Term. voltage (V)	92	165	237	303	349	382	415	438	456	469

(a) Draw the open-circuit characteristic curve of the dc generator at 1400 r.p.m.

(b) Determine the no-load terminal voltage of the dc generator at 1200 r.p.m. if the field circuit resistance is adjusted to 220 ohms.

(c) Determine the generated voltage, terminal voltage and power output of the generator at 1200 r.p.m. when it delivers 120 A to a load. The shunt field resistance is 220 ohms and the armature circuit resistance is 0.2 ohm. Neglect armature reaction.

16 2. A wye-connected, three-phase, 60-Hz, 4-pole alternator has 48 slots and 26 conductors per slot. The machine is lap-wound with double-layer. The coils span 11 slots. The alternator has a fundamental flux per pole of 0.06 Wb, a 3rd harmonic flux per pole of 0.005 Wb and a 5th harmonic flux per pole of 0.002 Wb. Determine the following:

(a) the pitch factor(s) of the winding, $K_{p_1} = 0.9914$ $K_{d_1} = 0.9577$
(b) the distribution factor(s) of the winding, $K_{p_3} = -0.9239$ $K_{d_3} = 0.6533$
(c) emf per coil, $K_{p_5} = 0.7934$ $K_{d_5} = 0.2053$
(d) the open-circuit phase voltage, and
(e) the open-circuit line-to-line voltage.

8 3. A three-phase ac synchronous generator is connected to a three-phase system at an infinite bus. With the help of a phasor diagram, explain what would happen if the prime-mover input of the synchronous generator is increased from its previous level while the excitation, the frequency and the terminal voltage are held at their previous levels.

15 4. A three-phase, wye-connected, 480-V, 30-Hp, 60-Hz, four-pole induction motor has the following equivalent circuit constants in ohms per phase referred to the stator:

Marks

$R_1 = 0.2$,

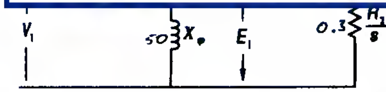


Figure 1. Equivalent circuit of an induction motor.

The motor is connected directly to a three-phase, 60-Hz, 480-V source. Determine the line current and the internal torque during starting.

5. A three-phase, 11000-V, 60-Hz, wye-connected, cylindrical-rotor synchronous generator is delivering 2000 kVA at 0.82 lagging power factor when connected to a three-phase, 11000-V, 60-Hz infinite bus. The machine has a resistance of 1.5 Ω and a synchronous reactance of 14 Ω per phase.

10 (a) Determine the excitation voltage, the power angle and real and reactive power output of the generator. Draw a phasor diagram showing all voltages and the armature current.

15 (b) The excitation of the generator is increased by 10 percent while the prime-mover power is held at its previous level. Determine the stator current, the power angle and the reactive power supplied by the generator. [Hint: Do not neglect the stator resistance.]

21 6. Mark the following statements as **TRUE** or **FALSE**. If you mark a statement as FALSE, briefly mention your reason(s) for doing so.

(a) The net effect of armature reaction in a dc machine can be considered as a reduction in the armature current.

(b) In a dc machine, pole face windings are used to neutralize the reactance voltage.

(c) In dc machines, interpoles are used to improve commutation.

(d) The speed of a dc shunt motor varies linearly as a function of its field flux.

(e) Short-pitched coils are used in three-phase alternators to improve the waveform of the voltage.

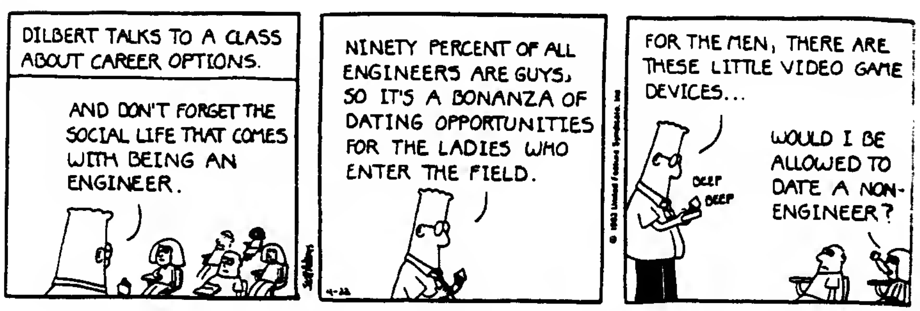
(f) Synchronous generators connected to infinite buses usually operate at lagging power factors.

(g) A synchronous motor connected to an infinite bus can be operated at a leading power factor.

(h) Synchronous motors are self-starting and, therefore, can be started with a load.

- The flux produced by the stator of an induction motor rotates at synchronous speed.
- The rotor of an induction motor rotates at synchronous speed.
- The frequency of the voltage induced in the rotor of an induction motor would be 60 Hz, if the machine were supplied from a balanced, three-phase, 60 Hz source.
- In an induction motor, the maximum internal torque occurs when the rotor current is at its maximum.
- The magnitude of the maximum internal torque in an induction motor can be increased by increasing the rotor resistance, provided all other parameters remain constant.
- The no-load test of an induction motor is ordinarily taken at a frequency lower than the rated frequency with rated voltage applied to the stator.

THE END



DC MACHINES

EMF, and Electromotive Force: $e = \bar{v} \times \bar{B} l$, $f = \bar{i} \times \bar{B} l$, v = velocity, i = current, B = field, l = length, e = EMF, f = force

Lenz's Law: $e = -\frac{\delta\lambda}{\delta t} = -\frac{\delta(N\phi)}{\delta t}$, λ = flux linkage passed through, N = #turns, ϕ = flux

Avg. Generated EMF: $e_s = \frac{P\phi n Z}{60a}$, e_s = generated emf, ϕ = flux per pole, P = # poles, Z = # conductors, a = parallel paths, n = (RPM).

$$\theta_{ed} = \frac{P}{2}\theta_{mech}$$

	Generators	DC Motor: Shunt	DC Motor: Series
Terminal Voltage	$V_t = E_a - I_a R_a$		
Back EMF		$E_a = V_t - I_a R_a$	$E_a = V_t - I_a R_a - I_a R_f$
Back EMF/Speed	$E_a = K_a \phi_d \omega_m$	$E_a = K_a \phi_d \omega_m$	$E_a = K_a \phi_d \omega_m$
Electromagenetic Power		$P_e = E_a I_a$	$P_e = E_a I_a$
Input Power		$V_t I_L = V_t I_a + V_t I_f$	$V_t I_L = E_a I_a + I_a^2 R_a + I_a^2 R_f$
Output Power	$P_{rated} = V_{t\text{-}rated} I_{a\text{-}rated}$	$P_{out} = P_e$ - mech losses	$P_{out} = P_e$ - mech losses
Torque/Power		$T_e \omega_m = P_e = E_a I_a$	$T_e \omega_m = P_e = E_a I_a$
Torque/Current		$T_e = K_a \phi_d I_a$	$T_e = K_a \phi_d I_a$
Neglecting Saturation and armature reaction		$\phi_d = K_1 I_f$ $E_a = K_2 I_f \omega_m$ $T_e = K_5 I_f I_a$	$\phi_d = K_3 I_a$ $E_a = K_4 I_a \omega_m$ $T_e = K_6 I_a^2$

V_t = terminal voltage, E_a = generated emf, I_a = Armature current, I_f = field current, I_L = Load/Line current, Ra = armature resistance plus effecitve brush-commutator contact resistance, R_f = field resistance, ω_m = angular speed (radians) = $2\pi n/60$ where n = speed (RPM), P_e = Electromagnetic Power

Speed Regulation: $SR = \frac{N_{NL} - N_{FL}}{N_{FL}}$, N = speed

Voltage Regulation: $VR = \frac{V_{tNL} - V_{trated}}{V_{trated}}$, V_t = terminal voltage

SYNCHRONOUS GENERATORS (Round Rotor)

Voltage per coil: E_{coil} (rms) = $(2\pi/\sqrt{2}) f_n N \phi_n = 4.44 f_n N \phi_n$, f = frequency, N = #turns/coil, ϕ = flux/pole, subscript n = harmonic

Distribution factor: $Kd_n = \frac{\sin(0.5nm\alpha)}{m\sin(0.5n\alpha)}$, n = harmonic, m = # individual coils, α = slot angle, angle between adjacent slots (θ_{ed})

Pitch factor: $K_{p_n} = \sin\left(\frac{nP}{2}\right)$, P = pitch, n = harmonic

Voltage Generated: $E_{\phi n}$ (rms) = $4.44\, Kw_n f_n \phi_n N_t$, Kw_n = winding factor ($Kp_n\, Kd_n$), N_t = #turns/phase = (mN) where m = #coils, N = #turns/coil, ϕ_n = flux/pole, subscript n = harmonic